

CONFIDENTIAL

INTERIM ENGINEERING LETTER

ON

TRANSMITTER-RECEIVER PROJECT

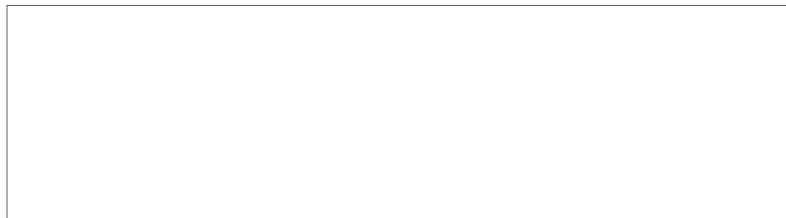
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Letter No. 2

Covering the Period
Oct. 1, 1954 to Nov. 30, 1954

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PURPOSE OF PROJECT

- a. Investigate possible new circuits which will improve the performance or simplify the construction of transistor radio receivers.
- b. Investigate ways in which the reliability of transistor circuits can be improved by reducing the effects of variations between components and by compensating for the effects of temperature.
- c. Investigate new types or improved variations of transistors as they become available to determine their applicability to radio receivers or transmitters.

PROJECT STATUS

A new type AGC circuit was investigated. New types of transistors have been measured to determine their applicability to radio receivers and transmitters.

SUMMARY OF WORK DONE THIS PERIOD

Several new types of transistors were measured to determine their applicability to radio receivers and transmitters.

Transistor	Power Gain (db)		Current Gain	
	455Kc	4Mc	1Kc	1Mc
SX160	25	9		
Texas (904A	25	9	54	13
Instr. (904	24	5	28	3
Hi-freq. (901	25	7	24	6
Silicon				
ZJ6 (General				
Electric Germanium				
Grown Junction)	23	3	33	4
Class C Amplifier & in Colpitts Oscillator				
		Power Output		Collector Efficiency
Texas Instr. X-15				
(medium power silicon)	21	2	200 mw.	40%

DETAILS OF WORK DONE THIS PERIOD1. Texas Instruments High Frequency Silicon Grown Junction Transistors Types 901, 904, and 904A

Three types of Texas Instruments silicon grown junction transistors were measured for (a) power gain, input resistance and output resistance, and (b) short-circuited current gain, as functions of frequency, and (c) saturation resistance and (d) leakage current. Tests were made at both room temperature and -45°C . The transistors measured were four 901's, three 904's and four 904A's.

Figure 1 shows the maximum, median and minimum values of power gain, input resistance and output resistance of eight SX160 transistors. These transistors are in metal cases and they showed quite good high frequency gain, i.e., 25 db at 455Kc and 9 db at 4 Mc.

Table 1 shows which characteristics of the silicon transistors are plotted in Figures 2 to 10.

TABLE I

Fig.#	Transistor Type	P.G. vs.Freq.	R _{in} vs.Freq.	R _o vs.Freq.	β_1 vs.Freq.	β_2 vs.Freq.	P.G. at 9.5Kc.	R _s
2	904A	x						
3	904A		x					
4	904A			x				
5	904	x	x	x				
6	901	x						
7	901		x					
8	901			x				
9	901, 904, 904A						x	x
10	901, 904, 904A				x	x		

P.G. = Power Gain
 R_{in} = Input Resistance
 R_o = Output Resistance

β_1 and β_2 = base to collector short circuited current gain

R_s = Saturation Resistance

All curves are plotted for values at room temperature and at -45°C .

a. Power Gain, Input Resistance and Output Resistance

Power gain was measured with input resistance matched and output conjugate matched. From Figures 2, 5 and 6 one can see that at 455Kc the power gain of the silicon transistors is comparable to that of the SX160's. From 1 Mc on, the 904A's are about equivalent to the SX160's while the 904's are inferior and the 901's are somewhere in between. A significant fact is that at -45°C the power gain of the silicon transistors does not vary much from that at room temperature. The average absolute deviation is 1.1 db.

The input and output resistances of the silicon transistors are plotted in figures 3, 4, 5, 7 and 8. In general the input resistance of the silicon transistor is higher and the output resistance is lower than those of the SX160's. These resistances in most cases are lower at -45°C than at room temperature.

b. Power Gain at 9.5Kc and Saturation Resistance

The power gain at 9.5Kc and the saturation resistance for the silicon transistors are plotted in figure 9. The power gain was measured in a matched condition. It is from 5 to 10 db better than that of the SX160's.

The saturation region of a transistor is the low voltage-high current region in the collector characteristics diagram where the a-c current gain is essentially zero. The saturation resistance is the collector-to-emitter resistance determined by the minimum voltage for any given voltage in the saturation region. The saturation resistance is measured with a fixed collector supply voltage and load resistance, viz. 12v. and 1000 ohms respectively. The bias current is increased until the collector current reaches saturation. The resistance is then determined. This resistance ranges from 180 ohms to over 800 ohms for the silicon units as compared to about 10 ohms for the SX160's. The resistance drops about 30% going from room temperature to -45°C.

c. Base to Collector Short-Circuit Forward Current Gain, β_1

β_1 was measured at 1 ma. collector current and β_2 at 10 ma for the 901's and 904A's, and 5 ma. for the 904's. The collector voltage was 5v. at all times. The results are plotted in figure 10. They show that at low frequency (up to 10Kc.) β drops about 30% to 50% going from room temperature to -45°C. At higher frequencies the deviation is increasingly less. For some low β values (3 or below) β is even slightly higher at the cold temperature than at room temperature.

d. Leakage Currents - I_{co} and I_{do}

The silicon units showed negligible I_{co} and I_{do} at room and cold temperatures.

2. General Electric Germanium NPN Grown Junction Transistor Type ZJ6

- a. Three General Electric npn type ZJ6 grown junction transistors were measured for power gain, input resistance and output resistance as functions of frequency both at room temperature and -45°C . The results are shown in figure 11. From these results it seems that the ZJ6's are equivalent to the 904's at room and low temperatures.
- b. Six ZJ6's were tested for β at $V_c = 6\text{v.}$ and $I_c = 1\text{ ma.}$ Measurements were made at frequency of 1Kc, 10Kc, 455Kc and 1 Mc and at temperature of -45°C , 25°C and 80°C . The results are shown in figure 12. They show temperature and frequency characteristics similar to the silicon units. β increases about 50% going from 25°C to 85°C and drops about 50% going from 25°C to -45°C at low frequency. At higher frequency the change is less definite depending on the particular transistor.
- c. The six units in (b) were measured for I_{co} at 80°C . I_{co} and I_{do} ranged from $13\mu\text{a}$ to $70\mu\text{a}$ and from 0.7 ma to over 5 ma at 6v. collector voltage respectively. However, at a collector voltage of 15v, five of the six units failed.

3. X-15 Silicon Junction Transistors

A number of preliminary investigations have been completed for five Texas Instrument type X-15 silicon, grown junction, npn transistors. These transistors have been characterized as medium power audio units by the Texas Instruments Co. They are rated at 1 watt collector dissipation at 25°C with heat sink and at 1/2 watt at 85° with heat sink.

The units were evaluated from small signal power gain, input resistance and output resistance as functions of frequency. V_c and I_c were 12 volts and 1 ma. respectively. Power gain was measured with the transistors operating in the common emitter stage. The input was resistance matched and the output conjugate matched. The results are shown in figure 13.

All of the units show small signal power gain in excess of 20db at 450 kilocycles. In each case power gain falls off at the rate of 6db per octave. As compared with SX-160's and 904's the matched output resistance is high; in excess of 25 kilohms at 450 kilocycles.

The input impedance for shorted output was measured over the frequency range from one kilocycle to 6 megacycles. The values obtained in the audio range are unusually high for the measured current gains. The input impedance falls off with frequency but fails to level off the highest frequency measured. This behavior is similar to that demonstrated by the type 904 silicon transistors. These results are shown in figure 14.

The I_C vs. I_B characteristics were obtained for the X-15 silicon transistors. Typical results are shown in figure 15 and figure 16. The droop in the curve of figure 15 shows the fall-off of β , current gain from base to collector, characteristic of junction transistors at high current levels. Three of the units demonstrated an appreciable β fall-off associated with lowering collector voltages. This occurred for current and voltage levels of about 10 ma. and 5 volts respectively as shown in figure 16. One unit showed a tendency to break down into heavy conduction from high current levels.

The performance of an X-15 silicon transistor in a Colpitts oscillator and in a tuned power amplifier was investigated. In both cases a power output of 200 milliwatts with 40% efficiency was obtained at 450 kilocycles.

These results are evidence that the X-15 is a transistor with a comparatively low resistance in series with the base lead, but with resistance and capacitance elements in series with the emitter and collector junctions. This would account for the input impedance which is initially high, but which fails to level off at high frequencies. It also serves to explain the loss of current gain at high current and low collector voltage which is responsible for the low efficiency obtained with the power amplifier.

In spite of the comparatively low efficiency obtained with the X-15's as power amplifiers, the overall performance has been quite encouraging. These transistors have proved to be able to take considerable abuse in terms of high collector dissipation and high collector voltage. Also the low $r_{bb'}$ (resistance in series between the base lead and the "intrinsic" transistor)* is very important in realizing the full capabilities inherent in the device. In particular (low) $r_{bb'}$ is much the more significant parameter in determining the maximum available power gain as contrasted to β , the short circuit current gain.

The resistance and capacitance elements in series with the emitter and collector leads are believed to be associated with the connection between the external lead and the silicon of the transistor. These elements reduce the power gain and limit the efficiency of the transistor. However, there is no reason to doubt that they can be significantly reduced or eliminated by further development and improvement of far fabrication techniques.

* L.J. Giacoletto, "Power Transistors for Audio Output Circuits," Electronics, January 1954, PP. 144-148.

FIG. 1. MEASUREMENTS OF 9 TYPE SX 60 TRANSISTORS

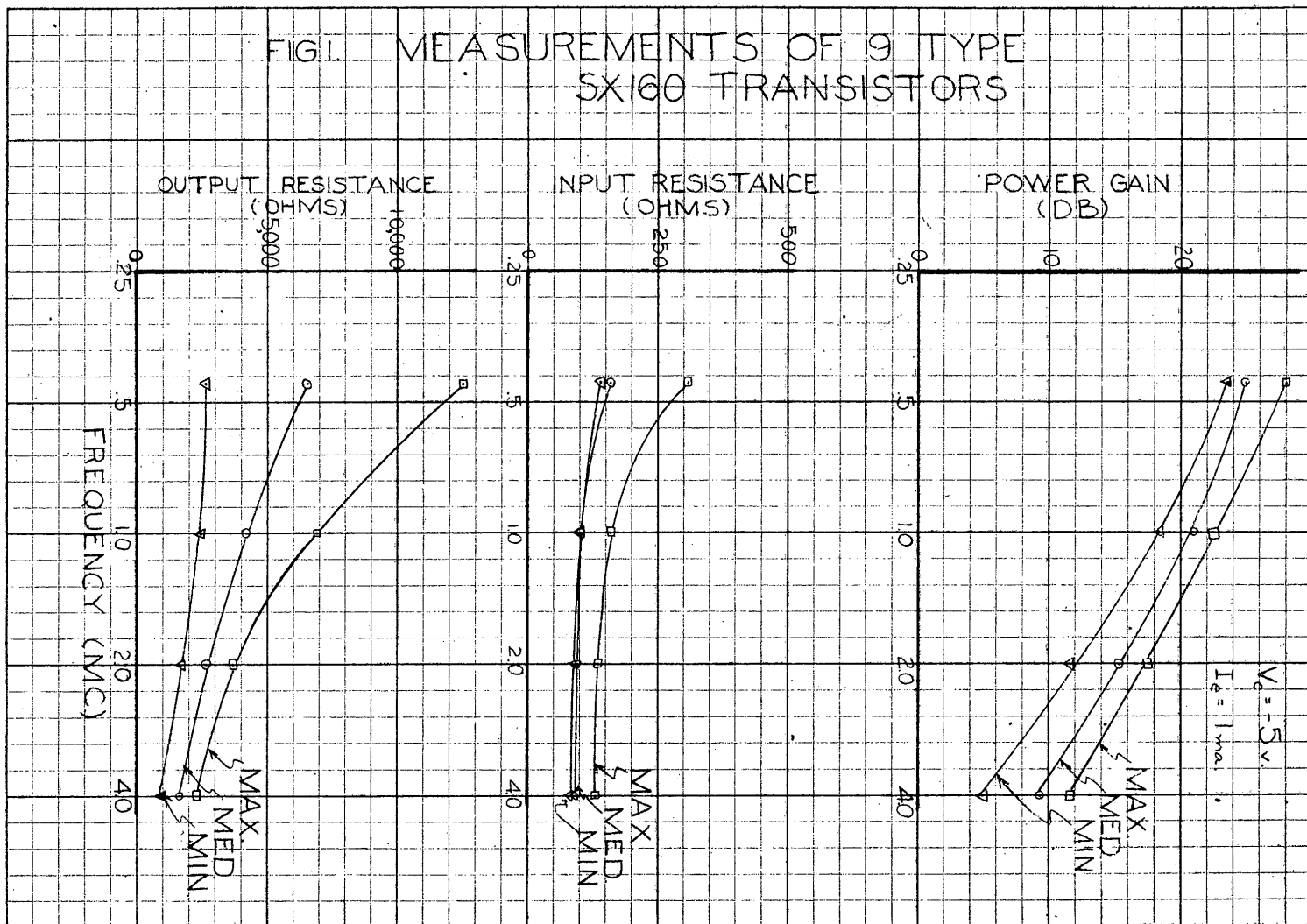
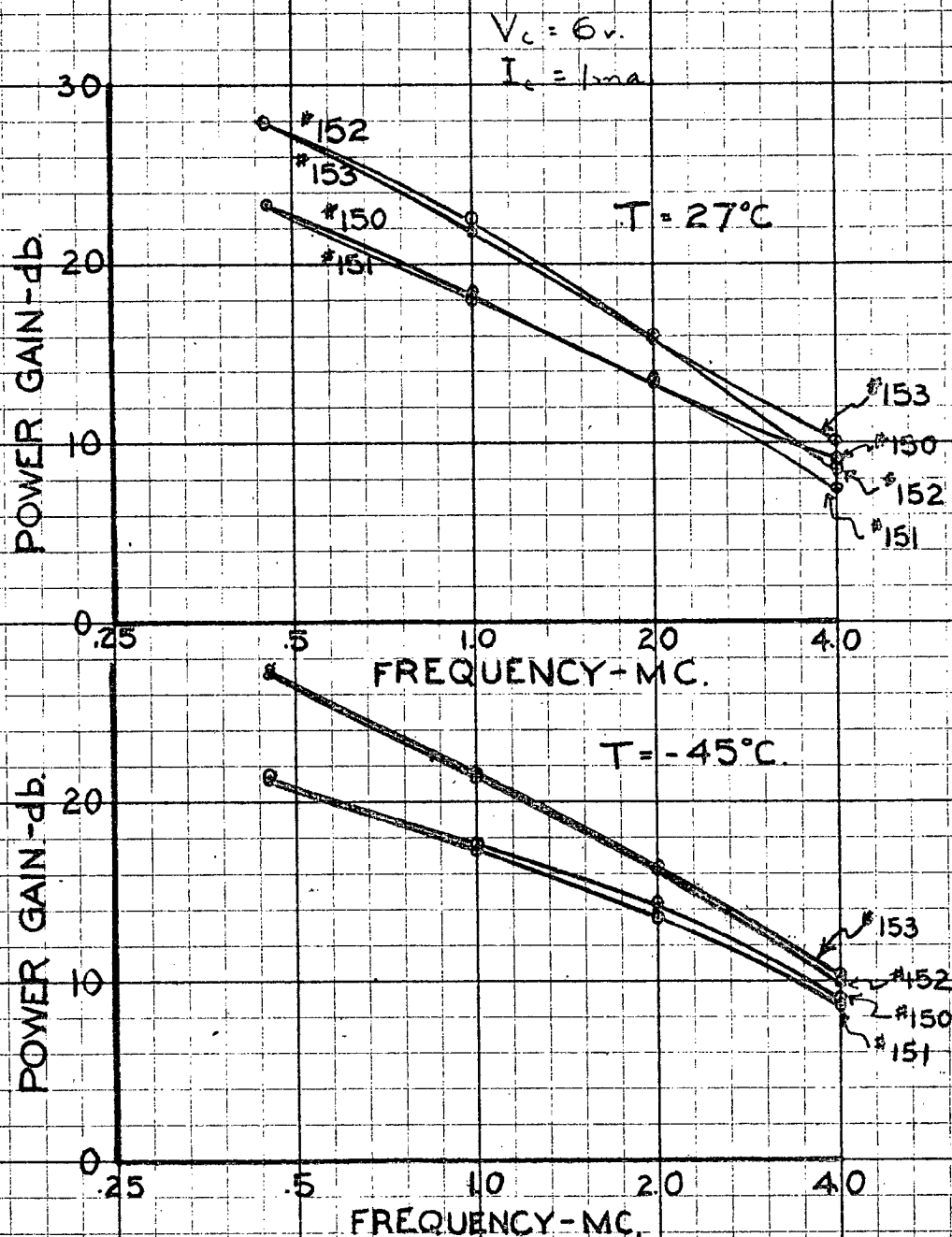
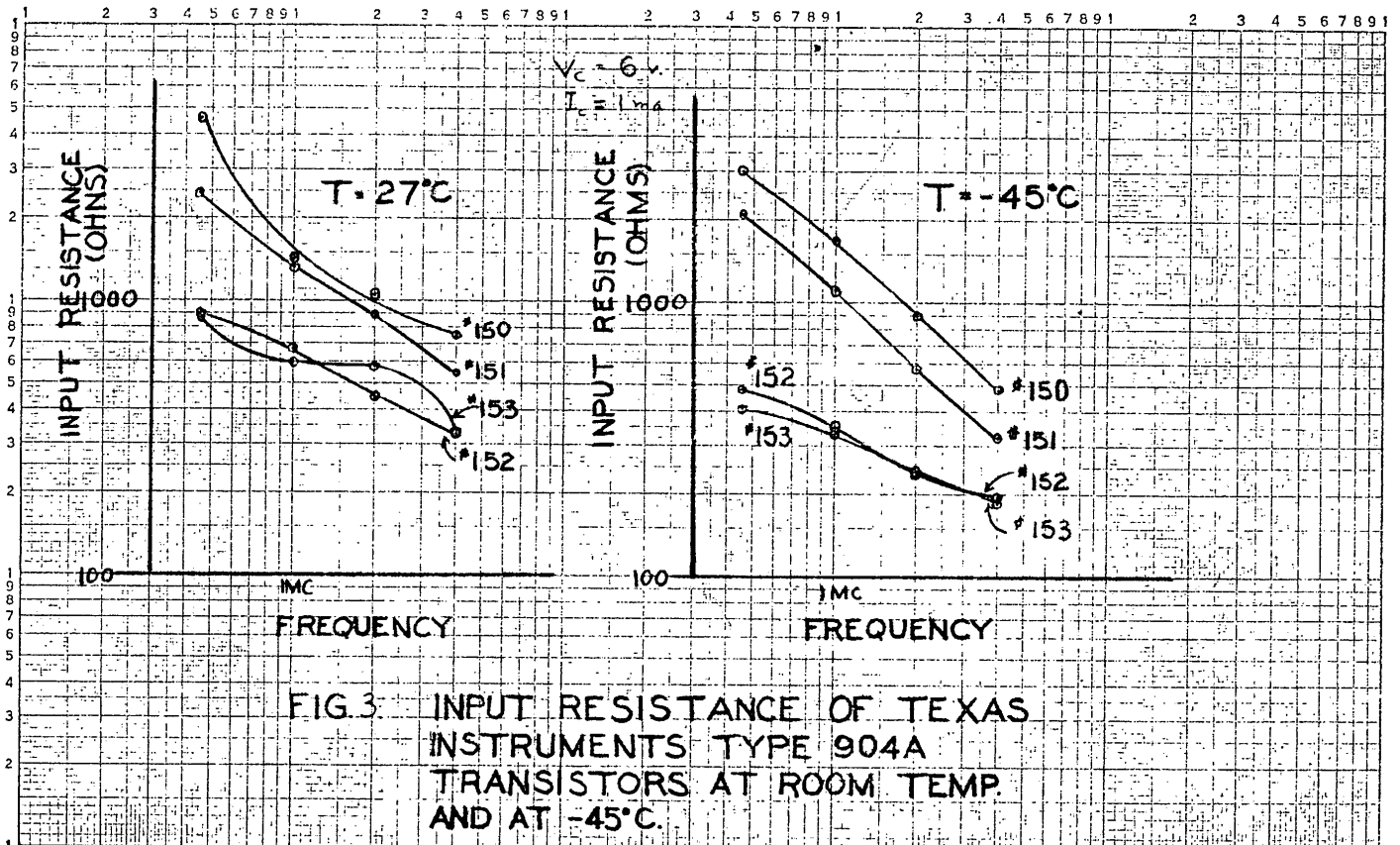
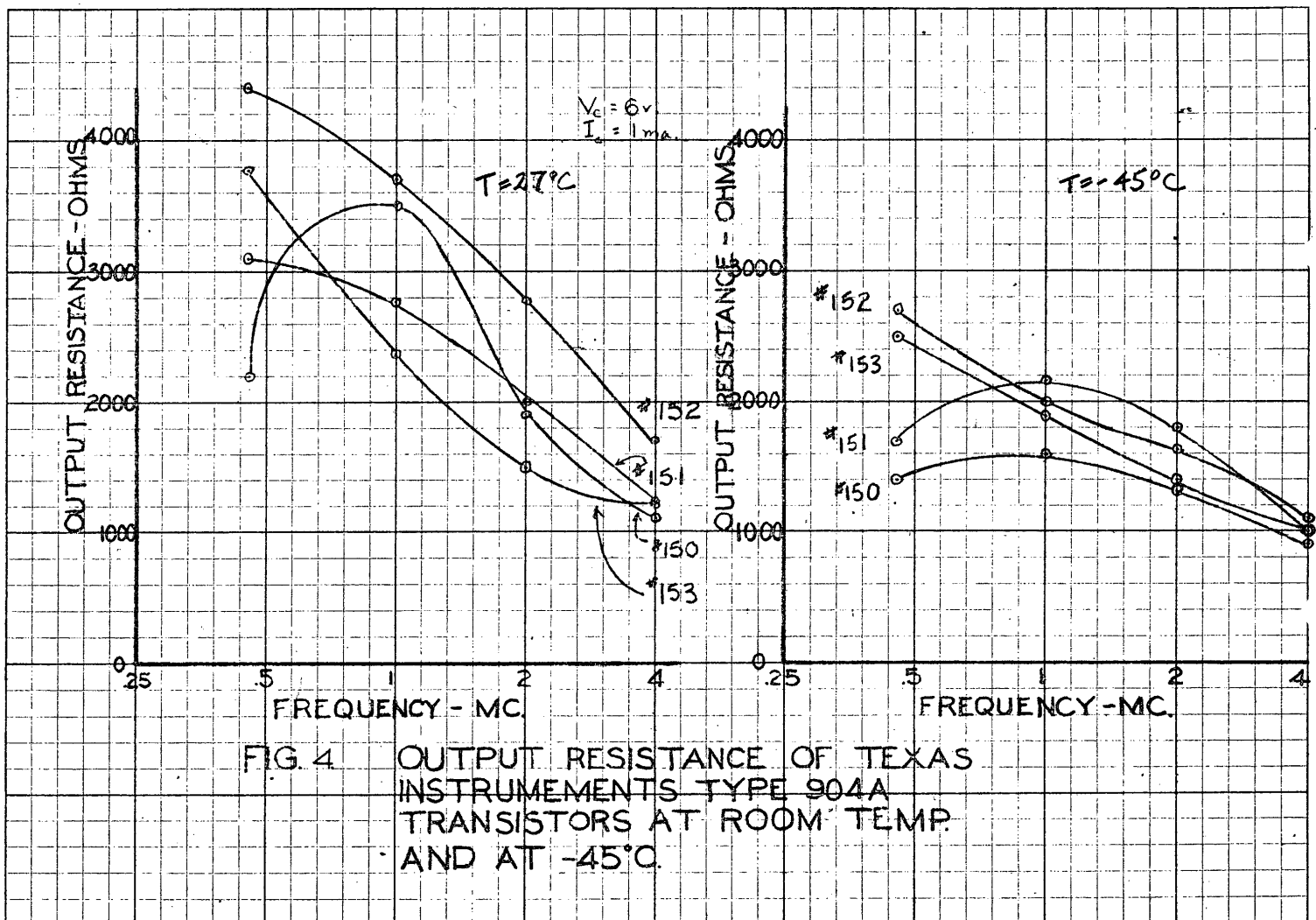


FIG. 2 POWER GAIN OF TEXAS
INSTRUMENTS TYPE 904A
TRANSISTORS AT ROOM
TEMP. AND AT -45°C .







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FIG. 5 MEASUREMENTS OF TEXAS INSTRUMENTS
TYPE 904 TRANSISTORS

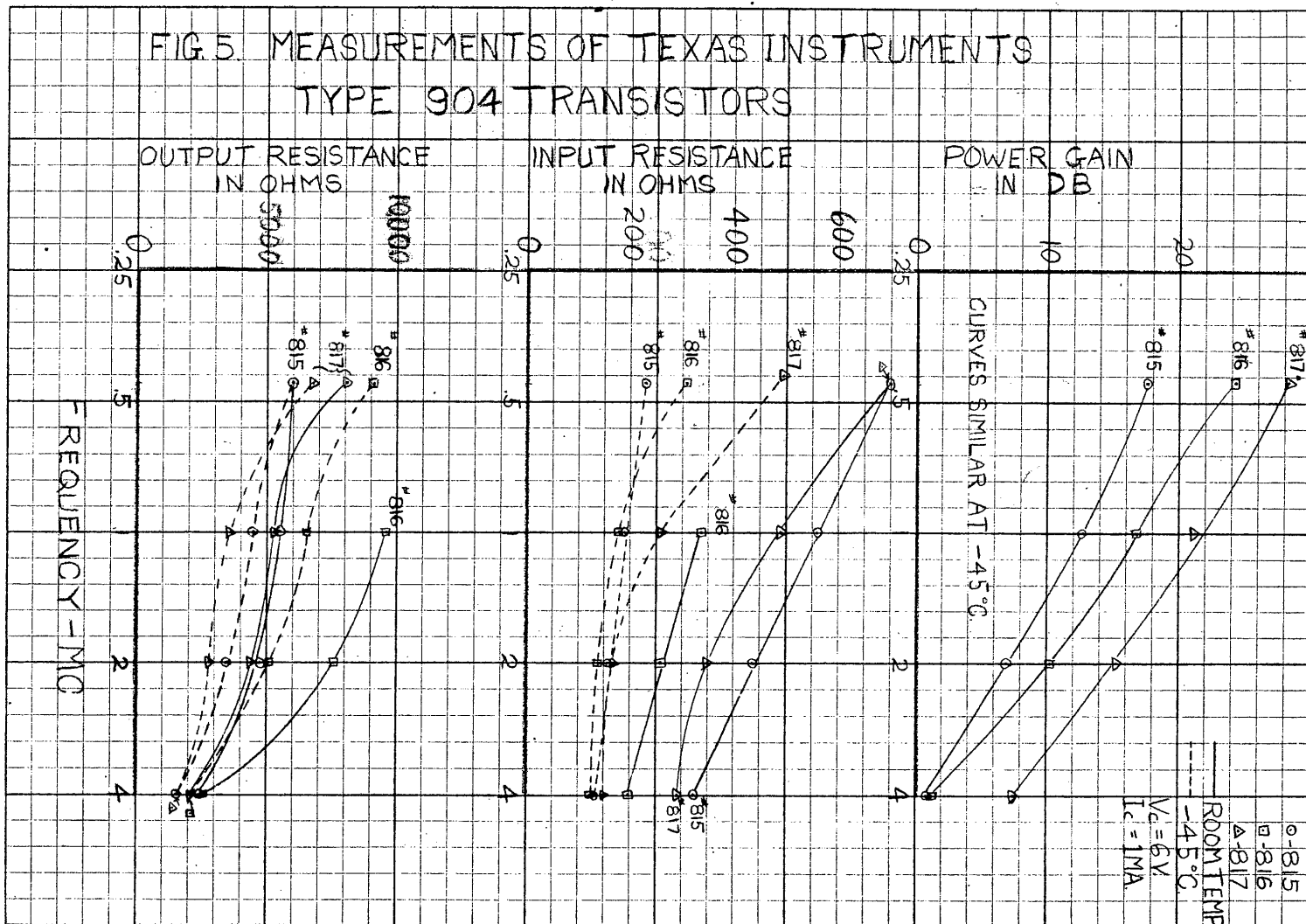
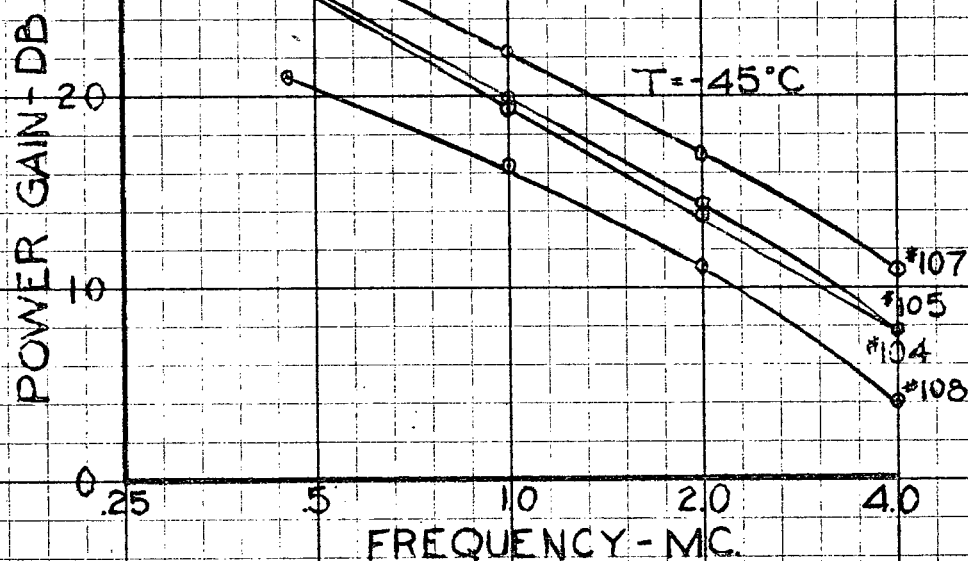
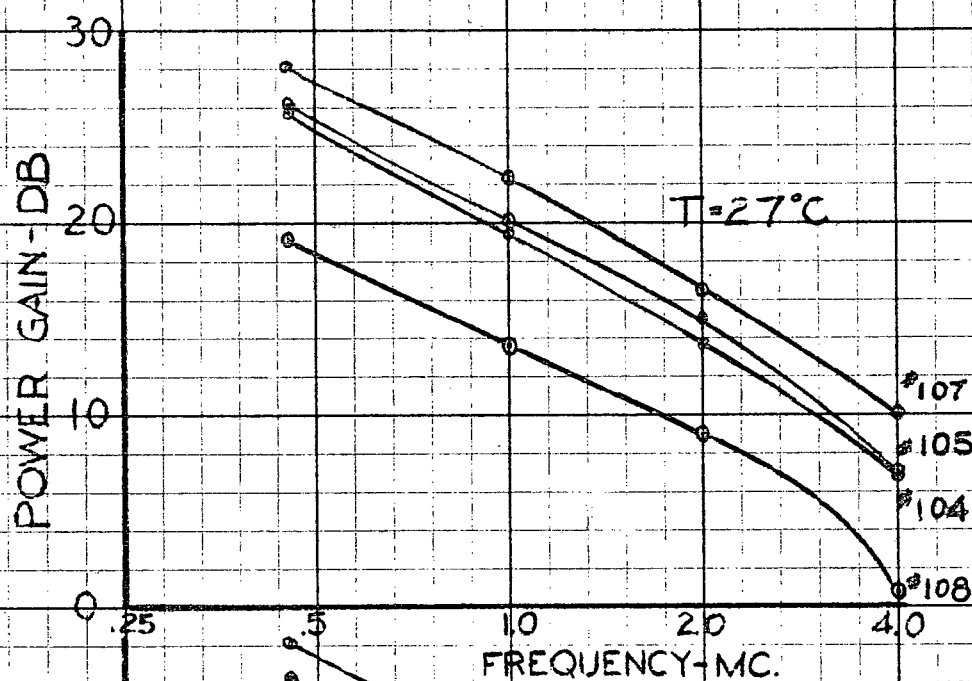
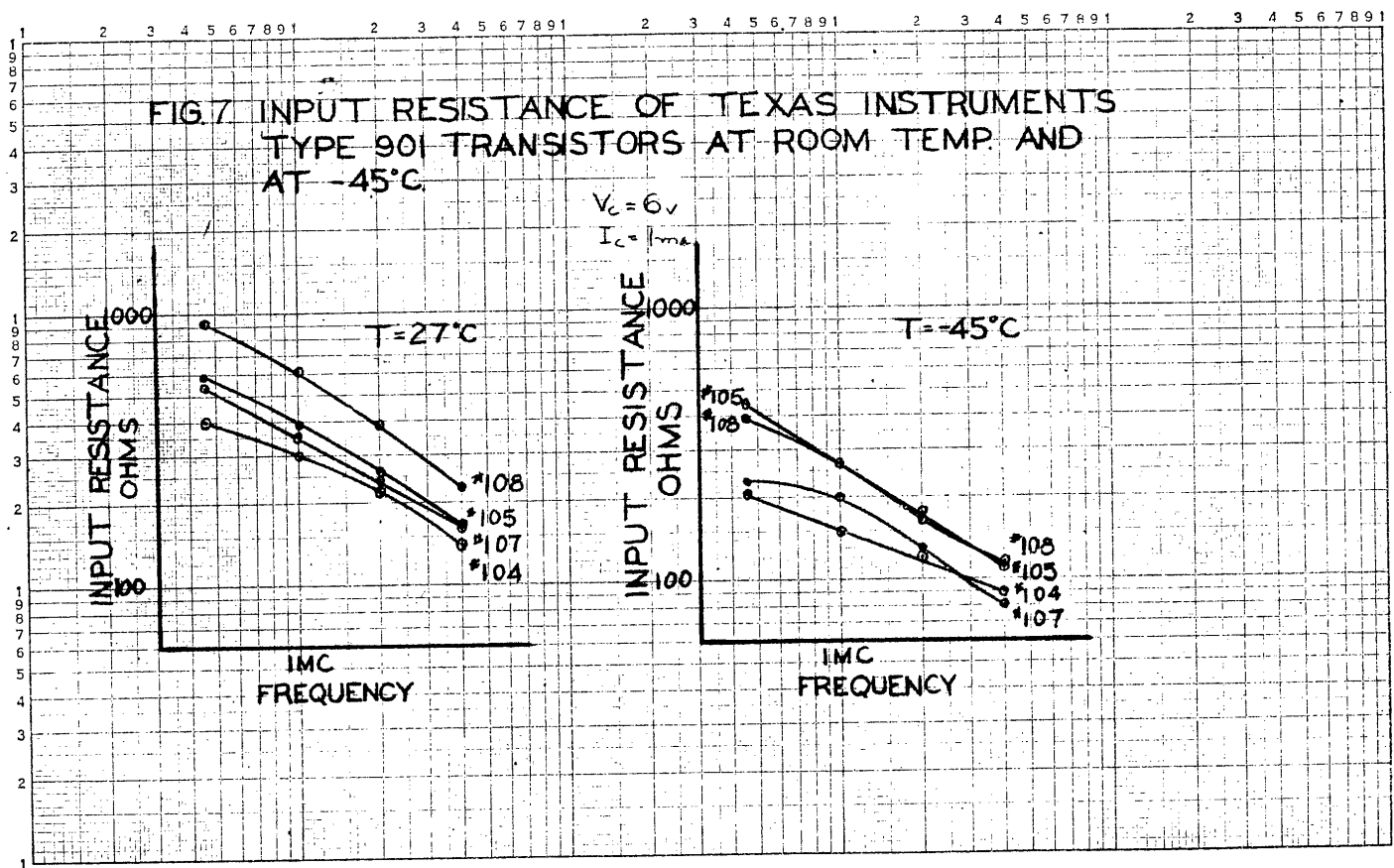
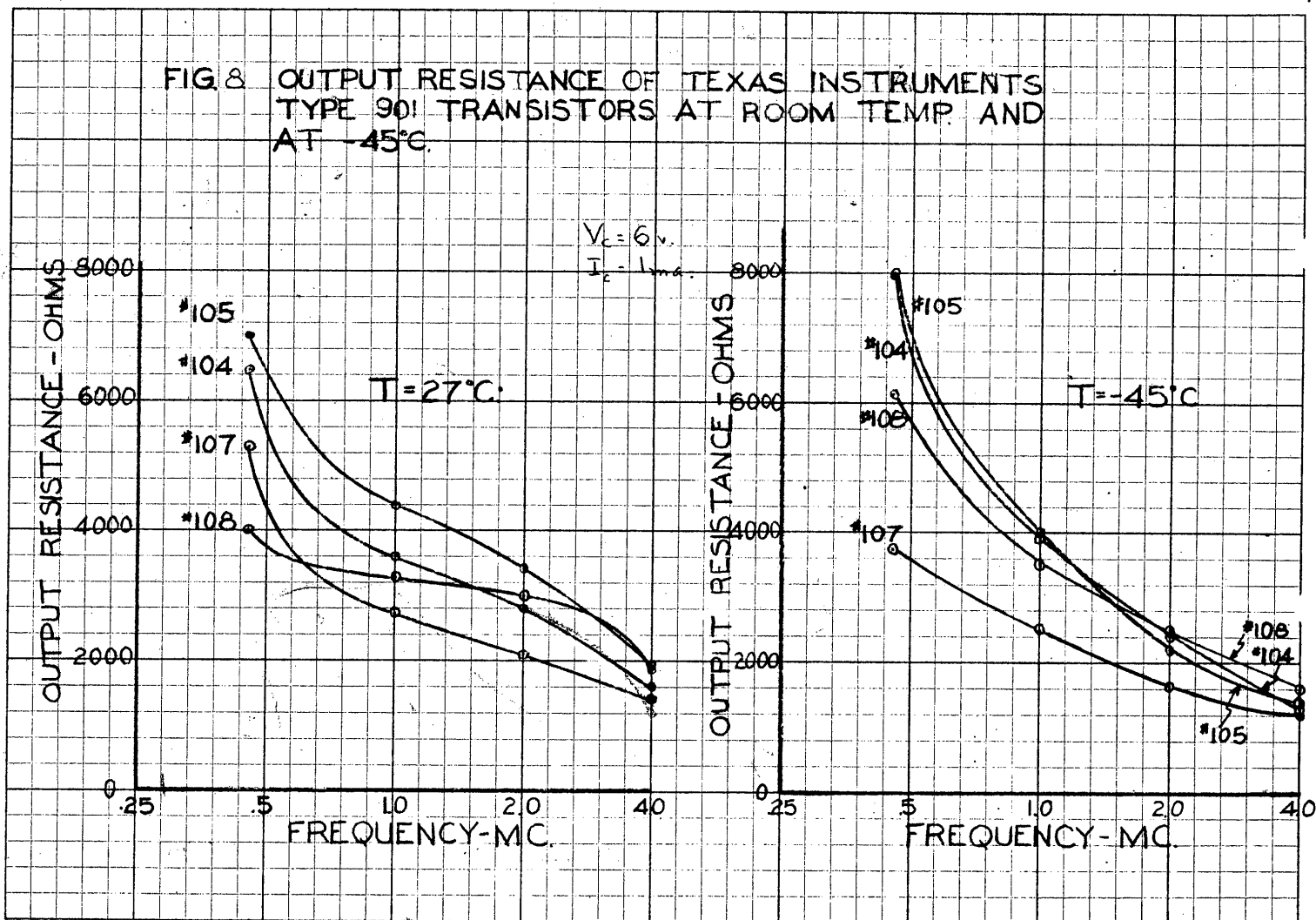


FIG. 6 POWER GAIN OF TEXAS
INSTRUMENTS TYPE 901
TRANSISTORS AT ROOM
TEMP. AND AT -45°C.

$V_c = 6v$
 $I_c = 1ma.$







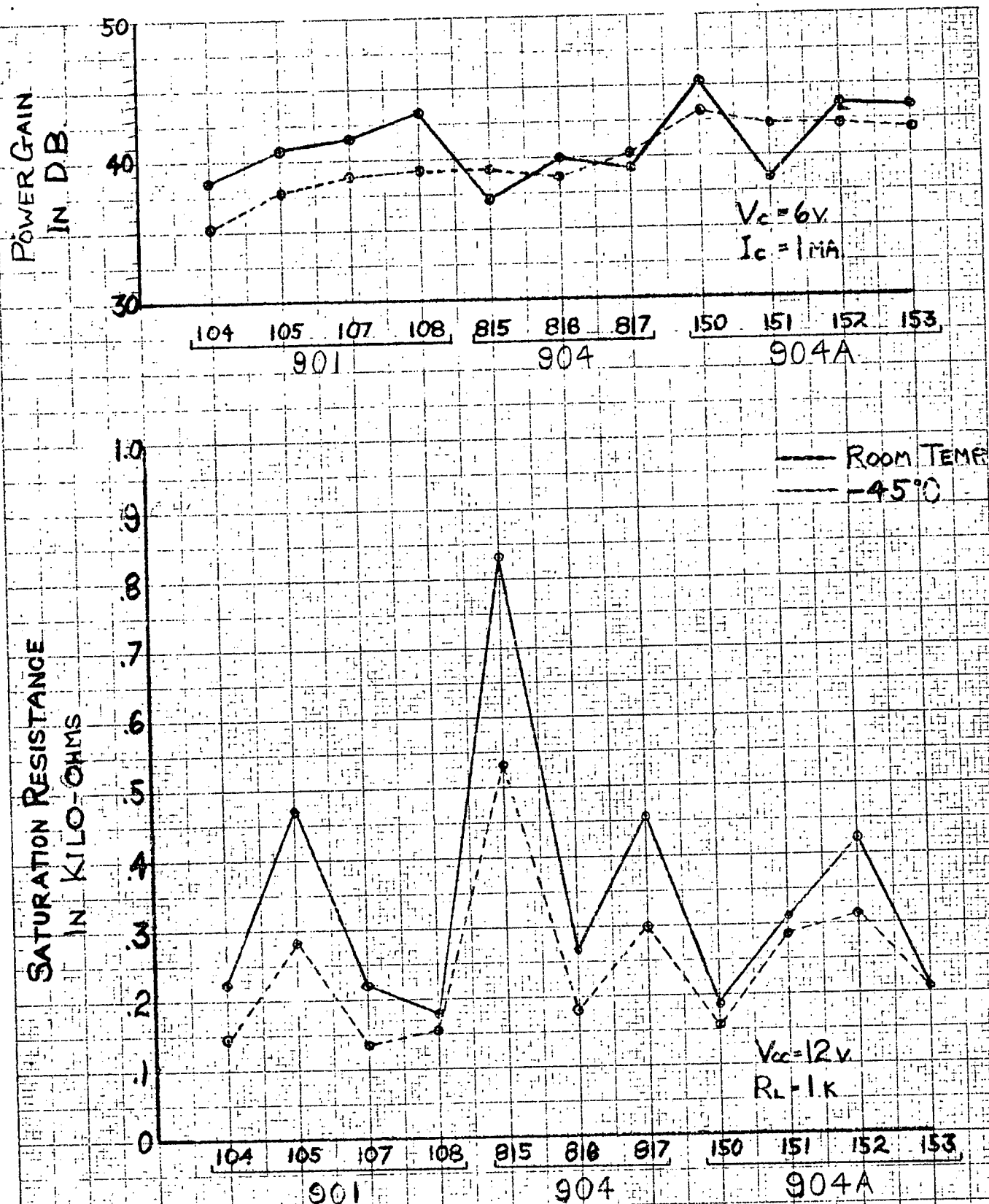
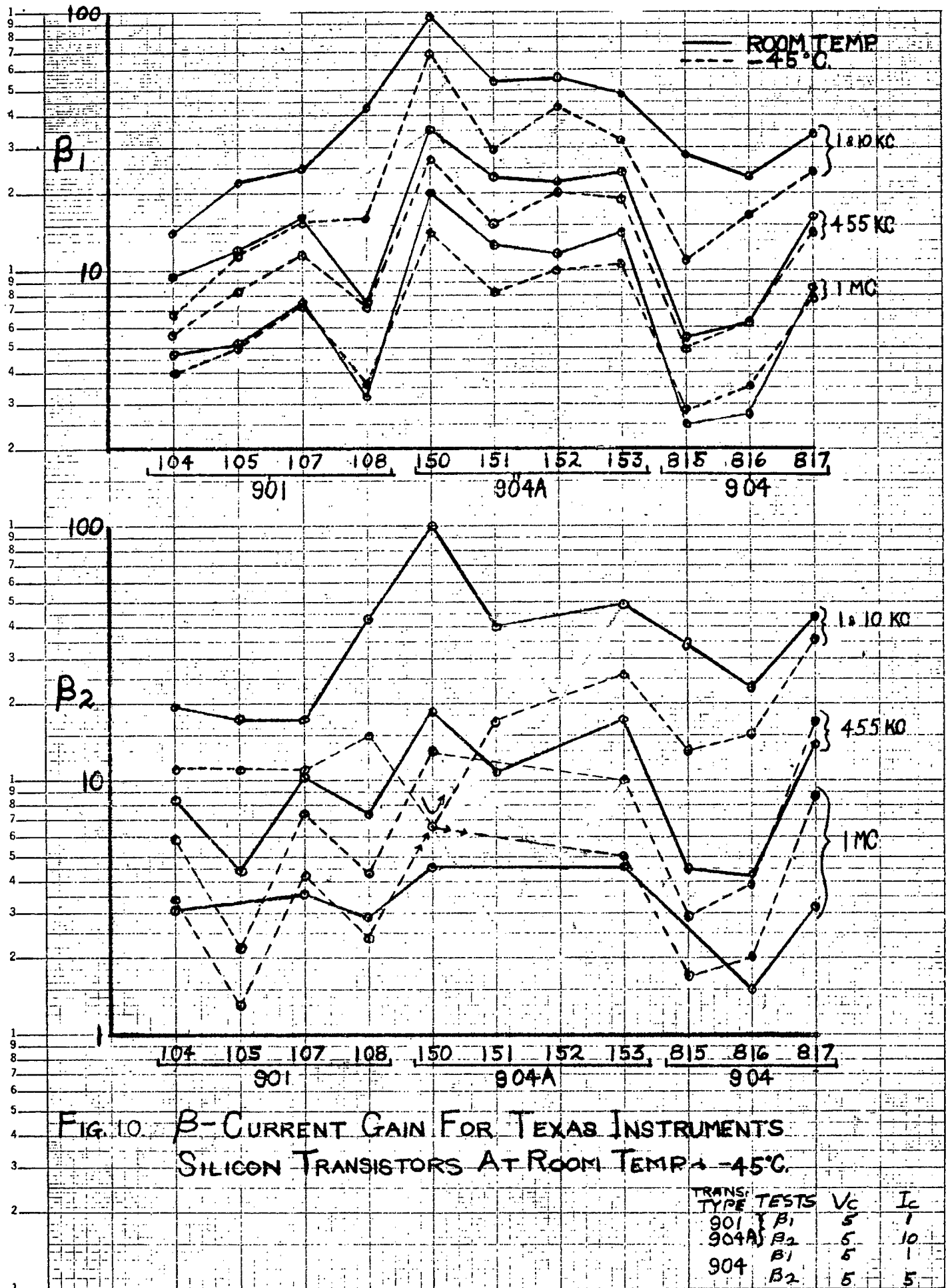
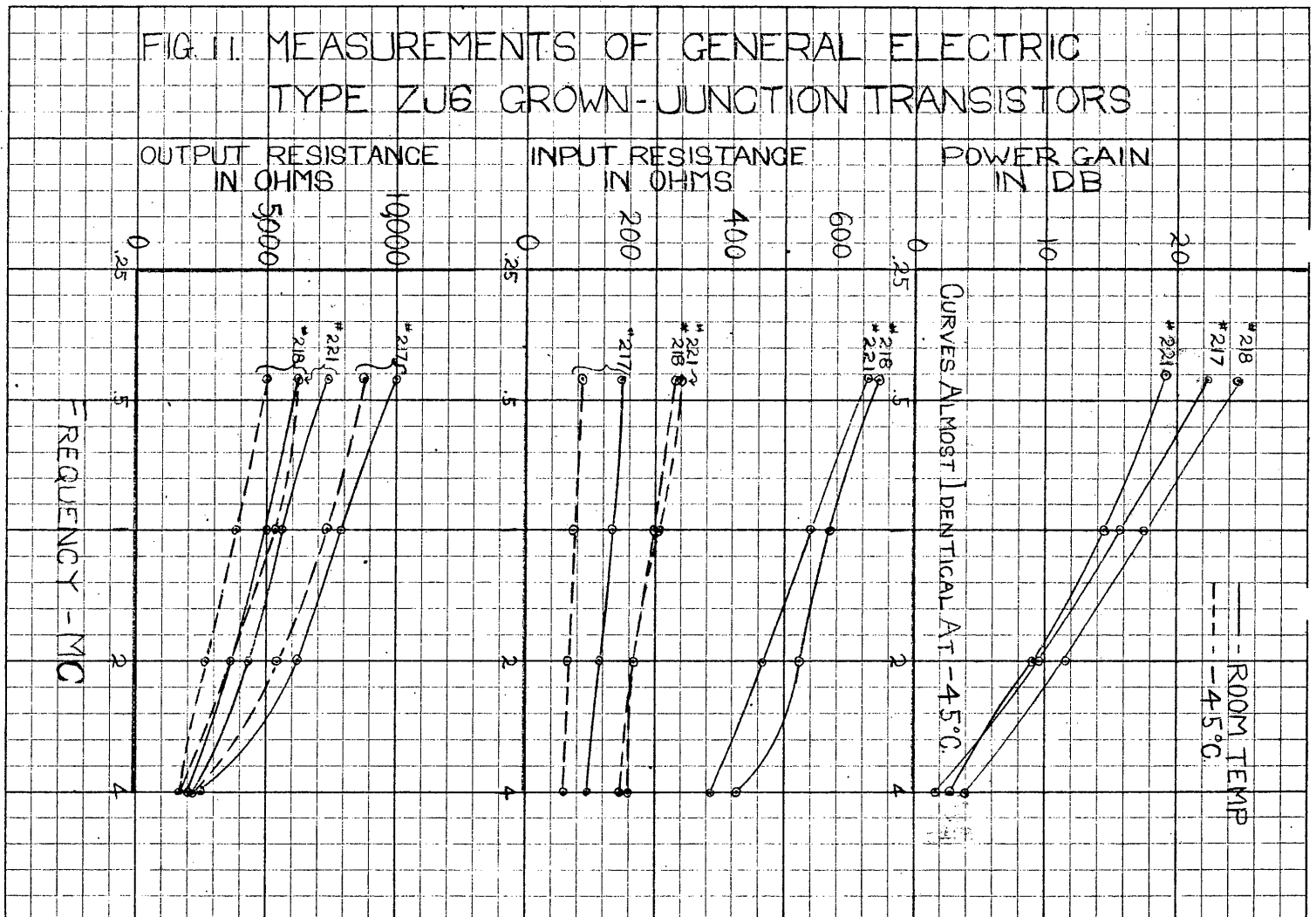


FIG. 9. POWER GAIN AT 9.5KC AND SATURATION RESISTANCE OF TEXAS INSTRUMENTS SILICON TRANSISTORS AT ROOM TEMP. AND $-45^{\circ}C$.



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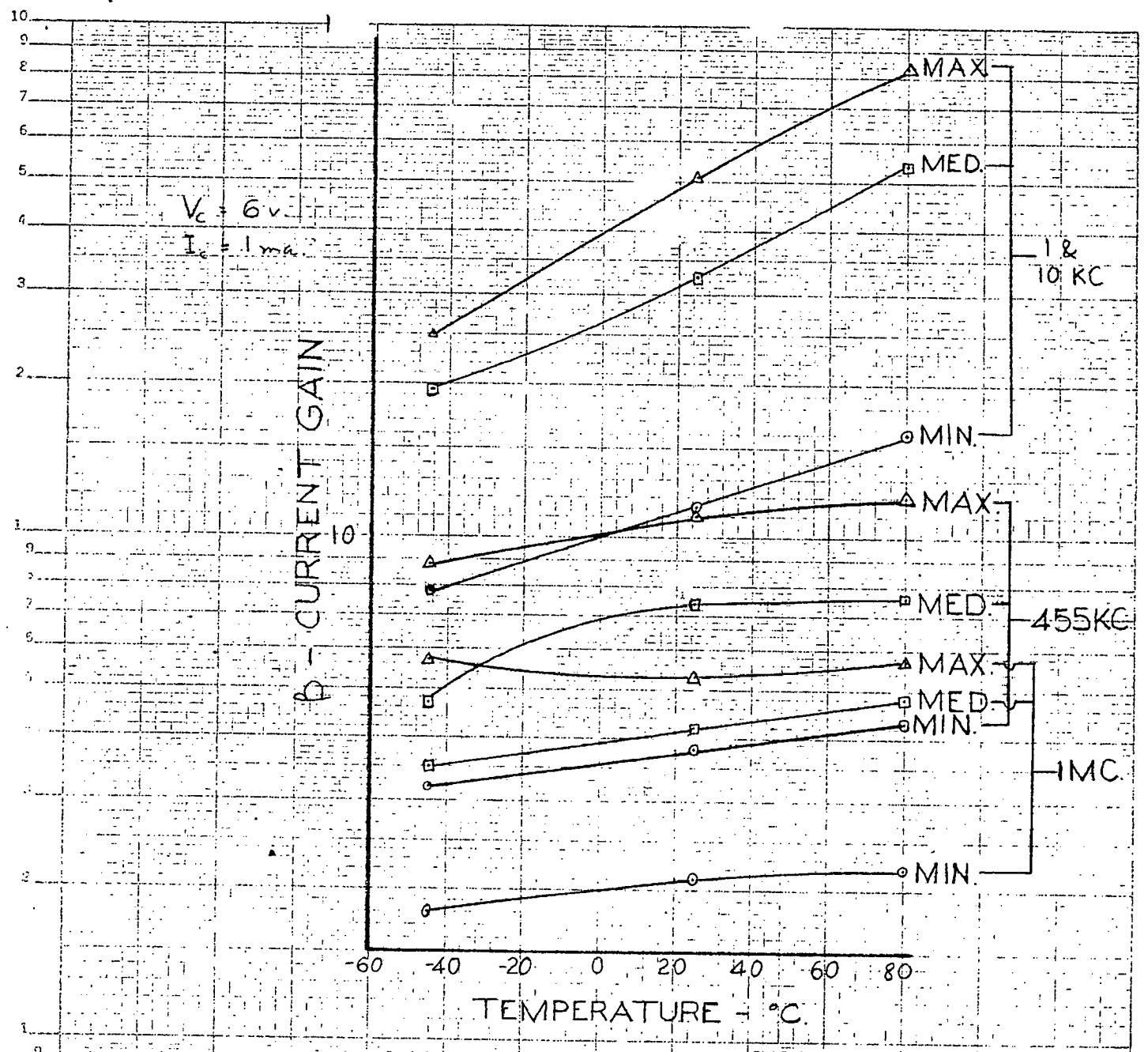


FIG 12 β - CURRENT GAIN FOR 6 GE ZJ6
GERMANIUM GROWN JUNCTION
TRANSISTORS

